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IS 3756 (2002): Method for Gear Correction - Addendum Modification for External Cylindrical Gears with Parallel Axes [PGD 31: Bolts, Nuts and Fasteners Accessories]

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"Knowledge is such a treasure which cannot be stolen"

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भारतीय मानक

गियर संशोधन की पद्धति — बाहरी बेलनाकार गियरों में समानान्तर अक्ष सहित परिशिष्ठ परिवर्तन

(पहला पुनरीक्षण)

Indian Standard

METHOD FOR GEAR CORRECTION — ADDENDUM MODIFICATION FOR EXTERNAL CYLINDRICAL GEARS WITH PARALLEL AXES

(First Revision)

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Gears Sectional Committee had been approved by the Basic and Production Engineering Division Council.

This standard was originally published in 1966. The revision of the standard has been undertaken to provide guidelines regarding the limits of addendum modifications of teeth and distribution of addendum modifications between mating gears through analytical equations and graphical representation, wherever necessary.

The gear is said to be corrected when the tooth form does not conform with the basic tooth form due to addendum modification.

This standard deals with the addendum modification for external spur and helical gears with parallel axes used in speed increasing and speed reducing gear pairs and of which the spur and helical gears are defined by the standard basic rack tooth profile according to IS 2535 : 1978 'Basic rack and modules of cylindrical gears for general engineering and heavy engineering (*second revision*)'.

In preparing this standard, considerable assistance has been derived from the following:

DIN 3992:1964 Addendum modification of external spur and helical gears.

Technical Report, ISO/TR 4467:1982 'Addendum modification of the teeth of cylindrical gears for speed reducing and speed increasing gear pairs'.

Maag Gear Book, Calculation and practice of gears, gear drives, toothed couplings and synchronous clutch couplings, 1990 edition.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

METHOD FOR GEAR CORRECTION — ADDENDUM MODIFICATION FOR EXTERNAL CYLINDRICAL GEARS WITH PARALLEL AXES

(First Revision)

1 SCOPE

This standard provides guidelines regarding the limits of addendum modifications of teeth, distribution of addendum modification between the gears of external cylindrical gear pairs with parallel axes, used for speed reducing and speed increasing applications.

2 SYMBOLS, NOMENCLATURE AND UNITS

Symbol	Description	Unit
a	Centre distance	mm
c	Bottom clearance	mm
d	Reference circle diameter	mm
d_a	Tip diameter	mm
d_m	Mean diameter	mm
h_{ap}	Addendum of the basic rack profile	mm
h_{fp}	Dedendum of the basic rack profile	mm
k	Addendum shortening coefficient	–
m	Module	mm
m_n	Normal module	mm
s_{an}	Constant tip thickness	mm
u	Gear ratio (Z_2/Z_1)	–
x	Addendum modification coefficient	–
z	Number of teeth	–
z_v	Virtual number of teeth	–
α	Pressure angle	deg
α_n	Normal pressure angle	deg
α_t	Transverse pressure angle	deg
α'_t	Working transverse pressure angle	deg
β	Helix angle	deg
β_b	Base helix angle	deg
λ	Factor	–
Σx	Sum of addendum modification coefficients	–
Σz_v	Sum of virtual number teeth, pinion and gear	–
inv	Involute function	rad

NOTE — Suffix 1 for pinion and Suffix 2 for gear.

3 ADDENDUM MODIFICATION

When gears are produced by a generating process, the datum line of the basic rack profile need not necessarily form a tangent to the reference circle of the generated gear. The tooth form may be altered by shifting the datum line from the tangential position. The involute shape of the tooth profile is retained and the effect is merely to use parts farther from or nearer to the origin of the involute.

The radial displacement from the tangential position is termed as addendum modification or profile shift. The addendum modification is considered positive when the displacement is away from the centre of the gear and it is considered as negative when in the direction towards the centre of the gear.

The effect of addendum modification on the tooth form is shown in Fig. 1. The load carrying capacity of the teeth without addendum modification as shown in Fig. 1a may be improved by the positive addendum modification as shown in Fig. 1b. An extremely large addendum modification results in an undesirable tooth form with pointed teeth as shown in Fig. 1c.

The teeth with different addendum modifications for 20° pressure angle are shown in Fig. 2.

The addendum modification coefficient x is the addendum modification divided by the module. Thus, the amount of addendum modification equals to $x.m$.

4 IMPORTANCE OF ADDENDUM MODIFICATION OF THE TEETH

4.1 The addendum modification gear teeth is carried out in order to avoid undercut, improve strength and running properties or to adjust the centre distance. The addendum modification is generally recommended in the following cases:

a) of gears with critical number of teeth;
b) of non-standard centre distance;
c) to obtain balanced strength; and
d) to obtain reduction in sizes.

However, load capacity and running equalities do not attain optimum values, but the gear pairs of this system have essentially better equalities than X-2000 gear pairs.

4.2 Cost of Manufacture of Gear Pair

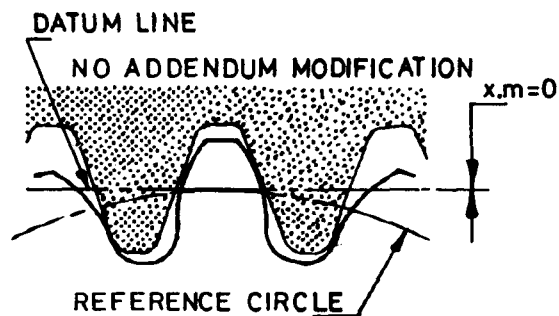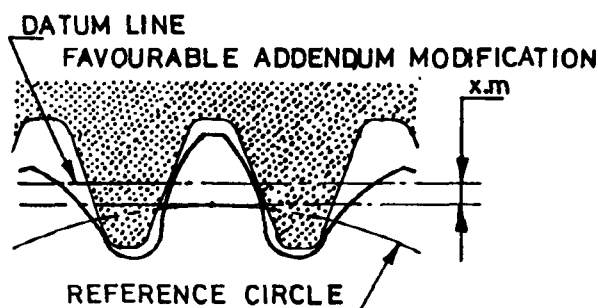The value of addendum modification of teeth depends solely, during manufacture, on the relative position of

DATUM LINE

NO ADDENDUM MODIFICATION

x.m=0

REFERENCE CIRCLE

FIG. 1a

DATUM LINE

FAVOURABLE ADDENDUM MODIFICATION

x.m

REFERENCE CIRCLE

FIG. 1b

DATUM LINE

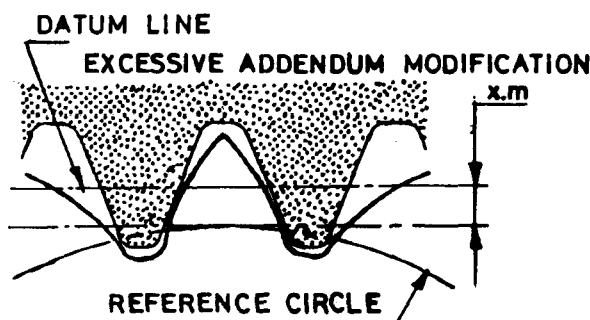EXCESSIVE ADDENDUM MODIFICATION

x.m

REFERENCE CIRCLE

FIG. 1c

Fig. 1 Gears (Meshing with the Generating Rack Profile) of Identical Module, Identical Reference Diameter and Identical Number of Teeth, But with Different Addendum Modification $x. m$

the gear to be cut and the cutter. Hence, the influence of addendum modification on the cost of toothed gears is nil in the majority of cases.

4.3 Influence on the Normal Wear of a Gear

The addendum modification of teeth results in a decrease in specific slipping of tooth flanks and consequently in a decrease in the normal wear of the tooth flanks.

4.4 Influence on the Load Capacity of the Gear

An increase in the sum of addendum modifications of gear pair results in increase in the load capacity of gear tooth under contact pressure (pitting) and also the bending strength at the root of the teeth.

4.5 Influence on the Shape of Teeth (*see* Fig. 1)

An increase in the addendum modification of the teeth of a gear causes an increase in root thickness and a decrease in tip thickness. The decrease in the addendum modification of the teeth has the reverse effect on tip and root thickness and below a given value which depends on the number of teeth in the gear in question, the addendum modification causes cutter interference which grooves the tooth root. The interference cause weakening of the gear tooth and poor functioning resulting in noise, rapid wear, etc.

Hence, for each gear, there is a maximum value for the addendum modification which results in a pointed tooth and a minimum value causing cutter interference.
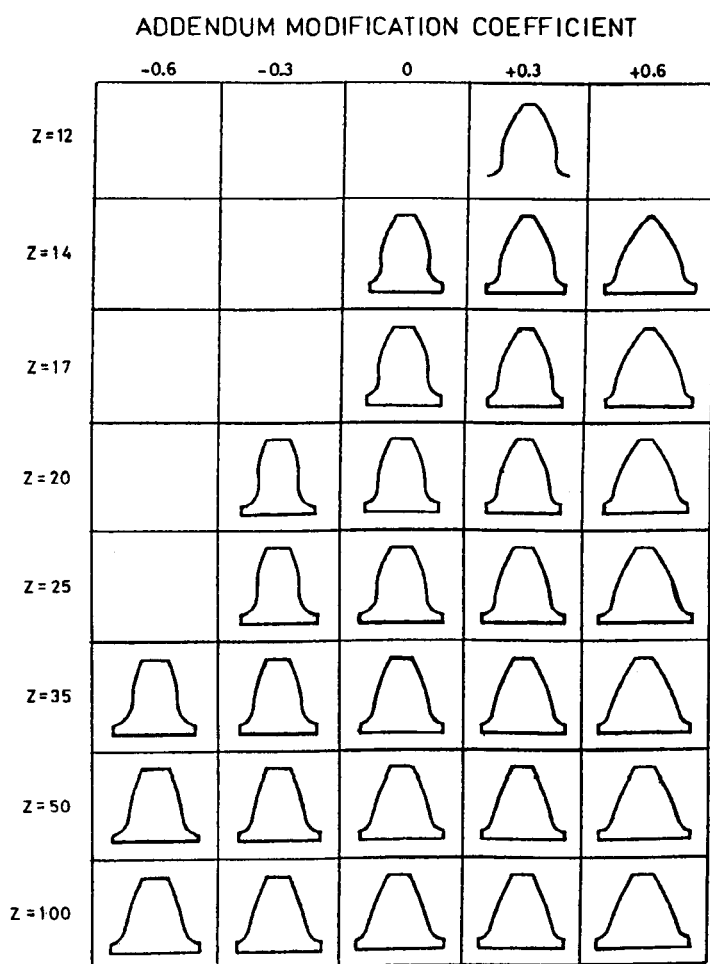
ADDENDUM MODIFICATION COEFFICIENT

FIG. 2 EFFECT OF THE NUMBER OF TEETH AND THE ADDENDUM MODIFICATION COEFFICIENT x ON THE TOOTH FORM FOR $\alpha = 20°$, $h_{ap} = 1.0$ m, $h_{fp} = 1.25$ m

4.6 Influence on Contact

An increase in the addendum modification of the teeth of the mating gears causes a slight decrease in the contact ratio of the gear pair. Hence, it is necessary to take into account while selecting the addendum modifications for high speed gear pairs to avoid speed irregularity and increase in the level of vibrations.

4.7 Influence on the Clearance at the Root of Teeth

Increase in the sum of the addendum modification in conjunction with small number of teeth in the gear pair may cause excessive increase in the bottom clearance resulting in detrimental phenomena, such as interference, lubricant pressure, etc.

4.8 Speed Reducing and Speed Increasing Gear Pairs

By considering the kinematics of a gear pair, it is ascertained that the slipping of the loading tooth during approach time, is in the opposite direction to the movement of the point of contact on the tooth flank. This results in a jamming effect which interferes with correct operation of the gear. A favourable solution is to reduce the approach time by giving the leading tooth as large an addendum modification as possible. For a given sum of addendum modifications, as small an addendum modification as possible shall be chosen for the driven gear.

For a speed reducing gear pair, the pinion is driving and it is preferable to increase the addendum modification of the pinion when the accompanying reduction is the addendum modification of the gear has no detrimental effect.

For a speed increasing gear pair, the gear is driving and in this case, a reduction in the addendum modification of the driven pinion is detrimental to the gear pair, if it becomes too great. To obtain a suitable speed increasing gear pair, an addendum modification

3

smaller than in the case of speed reducing gear pair shall be chosen without however going to an unacceptable value.

5 SUM OF ADDENDUM MODIFICATION COEFFICIENTS

5.1 Virtual Number of Teeth (z_v)

To include straight teeth and helical teeth in the identical formulae, the virtual number of teeth defined by the following equation is used:

$$z_v = \left[\frac{z}{\cos^2 \beta_b \cdot \cos \beta} \right]$$

$$\sin \beta_b = \sin \beta \cdot \cos \alpha$$

5.2 General

The choice of sum of addendum modification coefficients, Σx is arbitrary and depends on the centre distance variation of operating conditions desired. Too high or too low value of Σx may be harmful to the satisfactory functioning of the gear pair. Therefore, in this standard, conventional and recommended upper and lower limits are specified for Σx.

5.3 Conventional Limits

The following equations define the conventional limits for Σx which shall not be exceeded under any circumstances. Figure 3 is the graphical representation

of these limits. The shaded parts of Fig. 3 indicate the zones for special cases and the verification of the operating conditions is essential if Σx is chosen from these shaded areas.

5.3.1 *Upper Conventional Limit for Σx*

For $20 \leq \Sigma z_v \leq 80$, $\Sigma x = (100 + \Sigma z_v)/120$

For $80 < \Sigma z_v$, $\Sigma x = 1.5$

5.3.2 *Lower Conventional Limit for Σx*

For $20 \leq \Sigma z_v \leq 40$, $\Sigma x = 0.0375\,(40 - \Sigma z_v)$

For $40 < \Sigma z_v \leq 160$, $\Sigma x = 0.005\,(40 - \Sigma z_v)$

For $160 < \Sigma z_v$. $\Sigma x = -0.60$

5.4 Recommended Limits

The following equations define the recommended limits for the sum of addendum modification coefficients, within which there is no risk of any faulty operation and consequently no need for any type of verification. Figure 3 also gives the graphical representation of recommended limits for Σx.

5.4.1 *Upper Recommended Limit for Σx*

For $20 \leq \Sigma z_v$, $\Sigma x = 1.0$

5.4.2 *Lower Recommended Limit for Σx*

For $20 \leq \Sigma z_v \leq 60$, $\Sigma x = 0.025\,(60 - \Sigma z_v)$

For $60 < \Sigma z_v$, $\Sigma x = 0.0$

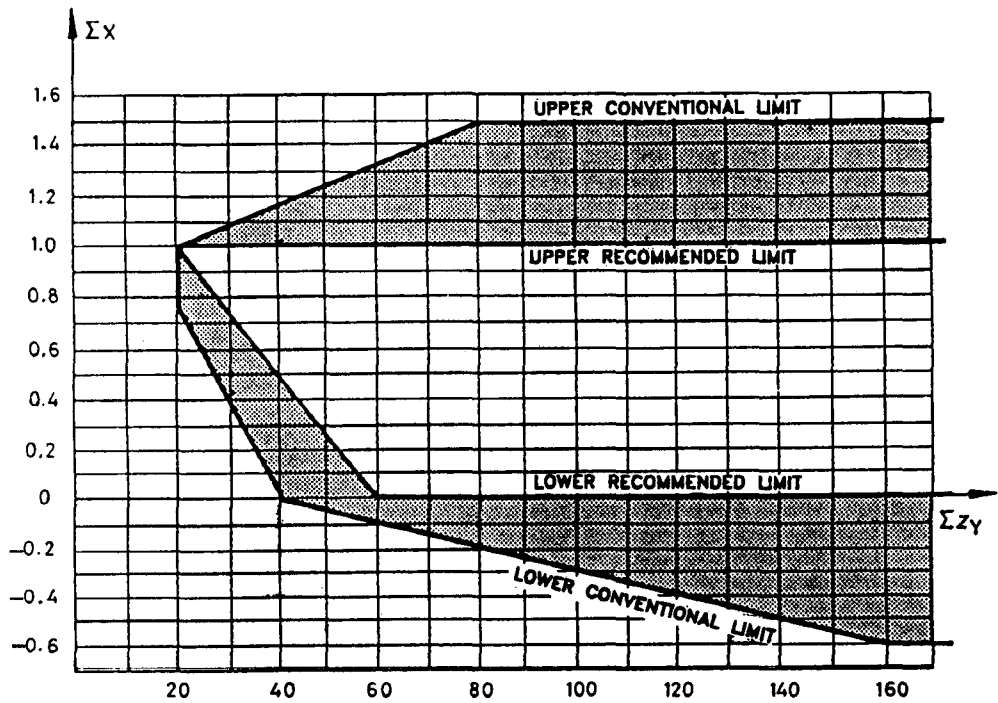The sum of the number of teeth (normal or virtual) of

FIG. 3 CONVENTIONAL AND RECOMMENDED LIMITS FOR THE SUM OF THE ADDENDUM MODIFICATION COEFFICIENTS AND ZONES FOR SPECIAL CASES

the gear pair shall in no case be less than 20 for addendum modification. Recommended sum of number of teeth is 24.

5.5 Selection of the Sum of Addendum Modification Coefficients

The choice of the sum of addendum modification coefficients shall be made taking into account the following:

a) For any increase in the sum of addendum modification coefficients, there is a corresponding increase in the breaking load capacity.

b) For any reduction in the sum of addendum modification coefficients, there is a corresponding increase in the contact ratio.

5.5.1 *Relation Between Centre Distance, Sum of the Addendum Modification Coefficients and the Operating Pressure Angle*

These relations are expressed as follows:

$$z_m = (z_1 + z_2)/2.0$$

$$d_m = (d_1 + d_2)/2.0$$

$$\tan \alpha_t = \tan \alpha /\cos \beta$$

$$a \cos \alpha'_t = d_m . \cos \alpha_t$$

$$\Sigma x = z_m (\text{inv } \alpha'_t - \text{inv } \alpha_t)/\tan \alpha$$

$$\text{inv } \alpha_t = \tan \alpha_t - \alpha_t . \pi/180$$

$$\text{inv } \alpha'_t = \tan \alpha'_t - \alpha'_t . \pi/180$$

6 DISTRIBUTION OF SUM OF ADDENDUM MODIFICATION COEFFICIENTS ON THE TWO MATING GEARS

For the distribution of the sum of addendum modification coefficients, Σx on the two mating gears, it is recommended to use the following formulae:

Addendum modification coefficient of the pinion:

$$x_1 = \lambda . \left[\frac{z_{v2} - z_{v1}}{z_{v2} + z_{v1}} \right] + \acute{s} . \left[\frac{z_{v1}}{z_{v2} + z_{v1}} \right]$$

For the straight teeth, $\beta = 0$ and $z_v = z$ and where the number of teeth of the two mating gears appear by their ratio.

$$x_1 = \lambda . \left[\frac{z_2 - z_1}{z_2 + z_1} \right] + x \left[\frac{z_1}{z_2 + z_1} \right]$$

or

$$x_1 = \lambda . \left[\frac{u - 1}{u + 1} \right] + x \left[\frac{1}{u + 1} \right]$$

$$x_2 = \Sigma x - x_1$$

The following values are recommended for λ:

$0.5 \leq \lambda \leq 0.75,$ for speed reducing gears

$0 \leq \lambda \leq 0.5,$ for speed increasing gears

For the gears with gear ratio exceeding 5, the distribution of sum of the addeÿÿp+2Xndum modification coefficients is calculated with $u = 5$.

However, the final choice of addendum modification coefficients, x_1 and x_2 shall be done within the limits specified at 7.

7 LIMITING VALUES OF THE ADDENDUM MODIFICATION COEFFICIENT

Too small an addendum modification coefficient gives rise to cutter interference and too large an addendum modification coefficient produces a pointed tooth. The exact values producing either cutter interference or pointed tooth for given virtual number of teeth are the lower and upper geometric limits respectively. The conventional and recommended limits are given below:

7.1 Conventional Limits

7.1.1 *Upper Conventional Limit*

For $6 \leq z_v \leq 10,$ $x = 0.60$

For $10 < z_v \leq 50,$ $x = 0.50 + 0.01 z_v$

For $50 < z_v,$ $x = 1.0$

7.1.2 *Lower Conventional Limit*

For $6 \leq z_v \leq 12,$ $x = 0.05 (18.0 - z_v)$

For $12 < z_v \leq 20,$ $x = 0.0375 (20.0 - z_v)$

For $20 < z_v \leq 50,$ $x = (20.0 - z_v)/60.0$

For $50 < z_v,$ $x = -0.50$

The graphical representation of conventional limits are given in Fig. 4.

7.2 Recommended Limits

7.2.1 *Upper Recommended Limit*

For $6 \leq z_v,$ $x = 0.60$

7.2.2 *Lower Recommended Limit*

For $6 \leq z_v \leq 50,$ $x = 0.025 (30.0 - z_v)$

For $50 < z_v,$ $x = -0.50$

The graphical representation of recommended limits are given in Fig. 4. The virtual number of teeth of a gear shall always have 6 as its lower limit. The shaded portions of Fig. 4 represent the zones in which the choice of addendum modification coefficient necessitates verification of the characteristics of the gear pair.
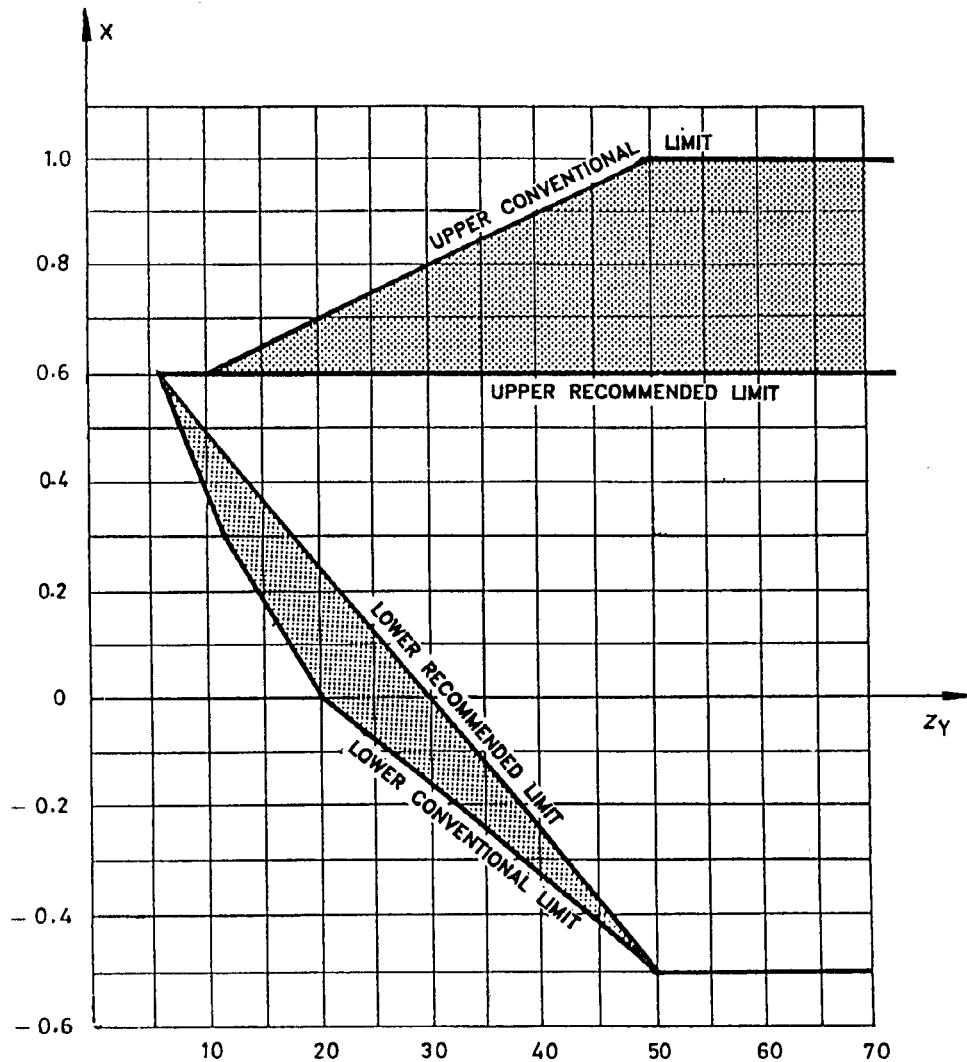
FIG. 4 CONVENTIONAL AND RECOMMENDED LIMITS FOR THE ADDENDUM
MODIFICATION AND ZONES FOR SPECIAL CASES

If the selected addendum modification coefficient is within the recommended limits as given in Fig. 4, it is not necessary to verify the operating characteristics of the gear pair.

7.3 Tip Thickness

The Fig. 5 gives the curves for constant tip thickness equal to 0, 0.1 m_n, 0.2 m_n, 0.3 m_n, and 0.4 m_n for a tooth depth in conformity with basic rack tooth profile without any reduction in the addendum.

Table 1 gives the values of addendum modification coefficient as a function of virtual number of teeth relating to these curves.

7.4 Reduction of the Addendum of Teeth

If it is desired to retain a tip thickness greater than 0.2 m_n, in some cases, it is useful to reduce the

addendum of the teeth. Reduction in addendum, 'k can be calculated using the following formulae:

For $x \le 0.6$, $k = 0.01\,(50.0\,x - 3.0\,z_v + 6.0)$

For $x > 0.6$, $k = 0.01\,(70.0\,x - 3.0\,z_v - 6.0)$

where $d_a = m_n \left[\dfrac{z}{\cos\beta} + 2.0\,(1.0 + x - k) \right]$

If k is calculated as negative, $k = 0$.

7.5 Values of Bottom Clearance

The sum of addendum modification coefficients of a gear pair has an effect on the value of bottom clearance. Figure 6 gives the curves representing Σx as a function of Σz_v, the constant clearance for a given curve and taking respectively the five values : 0.05 m_n, 0.1 m_n, 0.15 m_n, 0.2 m_n and 0.25 m_n. Table 2 gives some values relating to these curves.

6
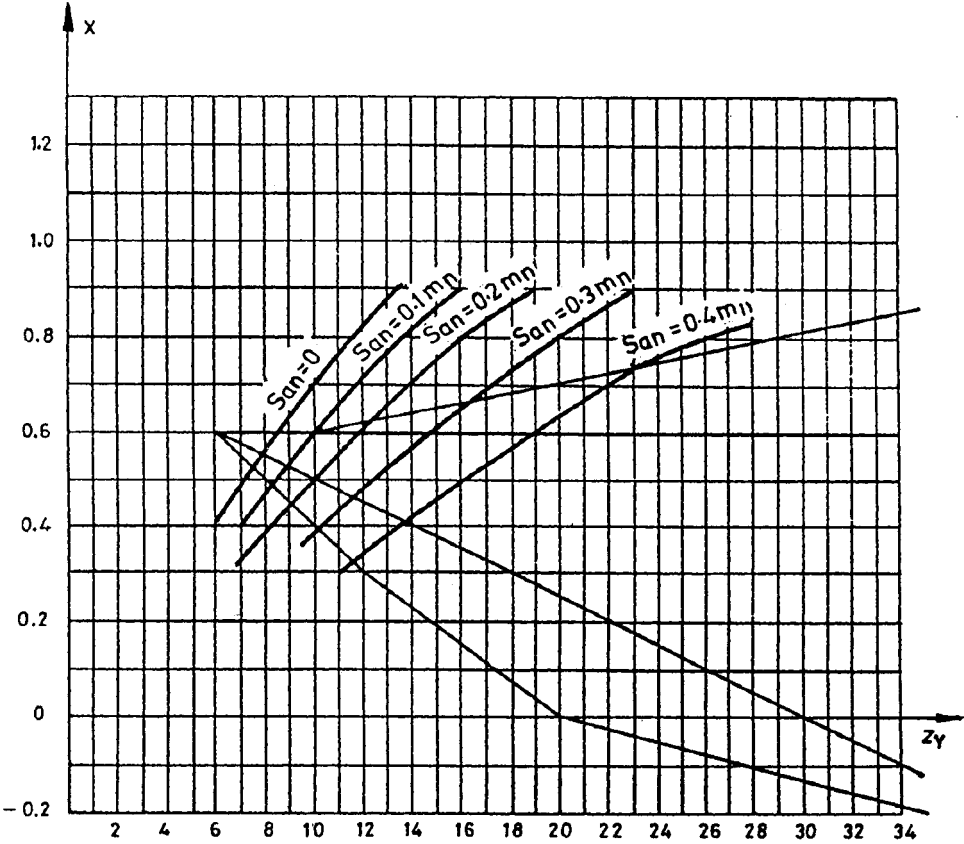
(NOTE — Line k = 0 is merged with $S_{an} = 0.2\ m_n$)
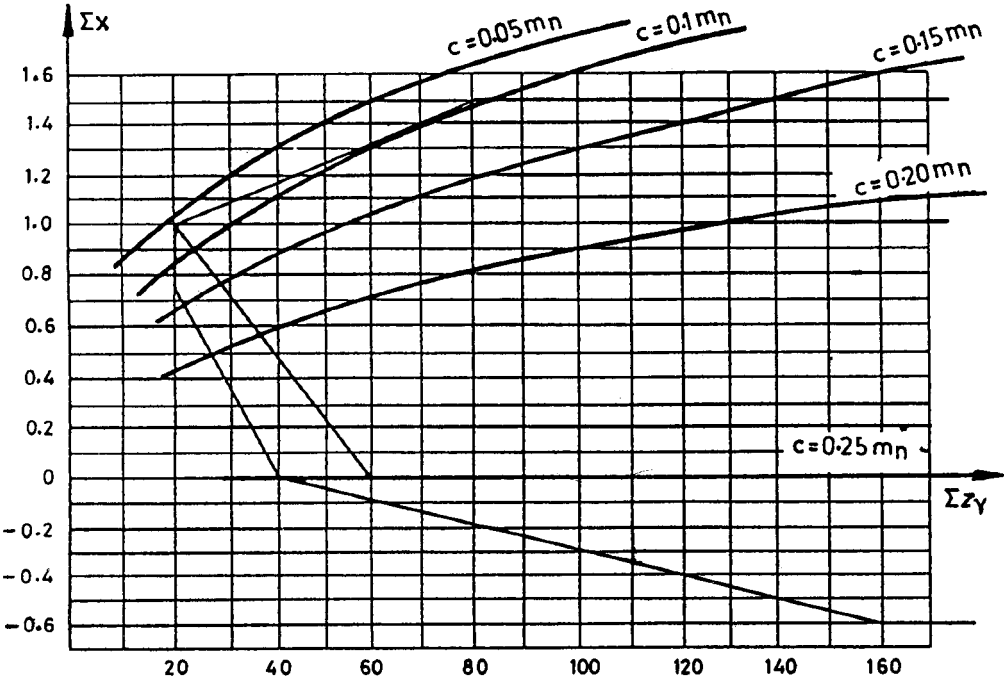
FIG. 5 CONSTANT TIP THICKNESSES

FIG. 6 CONSTANT BOTTOM CLEARANCES

7

Table 1 Values of *x* as a Function of z_v Giving the Tip Thicknesses, S_{an}

(Clause 7.3)

z_v	S_{an}		
	0.2 m_n	0.3 m_n	0.4 m_n
	x		
8	0.385		
9	0.443		
10	0.499	0.388	
11	0.552	0.436	0.309
12	0.602	0.481	0.350
13	0.650	0.525	0.389
14		0.568	0.427
15		0.609	0.464
16		0.648	0.499
17		0.687	0.533
18			0.567
19			0.599
20			0.631
21			0.662
22			0.692
23			0.722
24			0.751

NOTE — In the table, the intermediate values can be obtained by linear interpolation.

Table 2 Values of Σx for Various Values of Bottom Clearance Without Any Reduction in the Addendum

(Clause 7.5)

Σz_v	C			
	0.05 m_n	0.1 m_n	0.15 m_n	0.2 m_n
	Σx			
20	1.016	0.849	0.658	0.435
40	1.318	1.108	0.873	0.588
60	1.552	1.311	1.038	0.703
80	–	1.479	1.175	0.800
100	–	1.628	1.297	0.886
120	–	–	1.392	0.958
140	–	–	1.508	1.033
160	–	–	1.600	1.094

NOTE — In the table, the intermediate values can be obtained by linear interpolation.

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Amendments Issued Since Publication

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